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# Human Research Facility (HRF) Rack 2 Refrigerated Centrifuge (RC) Preliminary Fracture Control Summary Report

P/N SED46117400-301

CONTENTS

# 1.0 INTRODUCTION

The refrigerated centrifuge is intended to provide a system of separation of biological samples based on differing sample densities in a controlled temperature environment. RC will be a Commercial-Off-The-Shelf (COTS) unit, repackaged into a 12 Panel Unit (PU) drawer. It consists of two main components: (1) the refrigeration system and (2) the rotor assembly. The refrigeration method utilized by the centrifuge is vapor compression cycle. Vapor compression system consists of four components: compressor, condenser, evaporator, and expansion device.

During launch, landing, and on-orbit operation, the RC is rack mounted in a 12 PU active drawer. The refrigerated centrifuge will be used to separate biological samples such as blood and saliva. The front panel of the 12 PU drawer will open to expose the centrifuge rotor. The crewmember will select a rotor as identified in the experimental protocol procedures. The rotor is removed and replaced with the use of an Allen wrench that is provided as part of the centrifuge system. The samples will be loaded, and the door will be closed. The controls will be set for the appropriate time, temperature, rotor speed, and ramp up and down speeds.

Fracture control is implemented based on the Fracture Control Plan for Human Research Facility Payload and Racks, LS-71010. Structural analysis is performed based on the requirements in the Structural Verification Plan for Human Research Facility Payloads and Racks, LS-71012. RC design load factors are obtained from SSP Interface Requirements Document, SSP 57000, Revision D. Analysis results are documented in the HRF Rack 2 Refrigerated Centrifuge (RC) Stress Analysis Report, LMSEAT 33513, dated 10/2000.

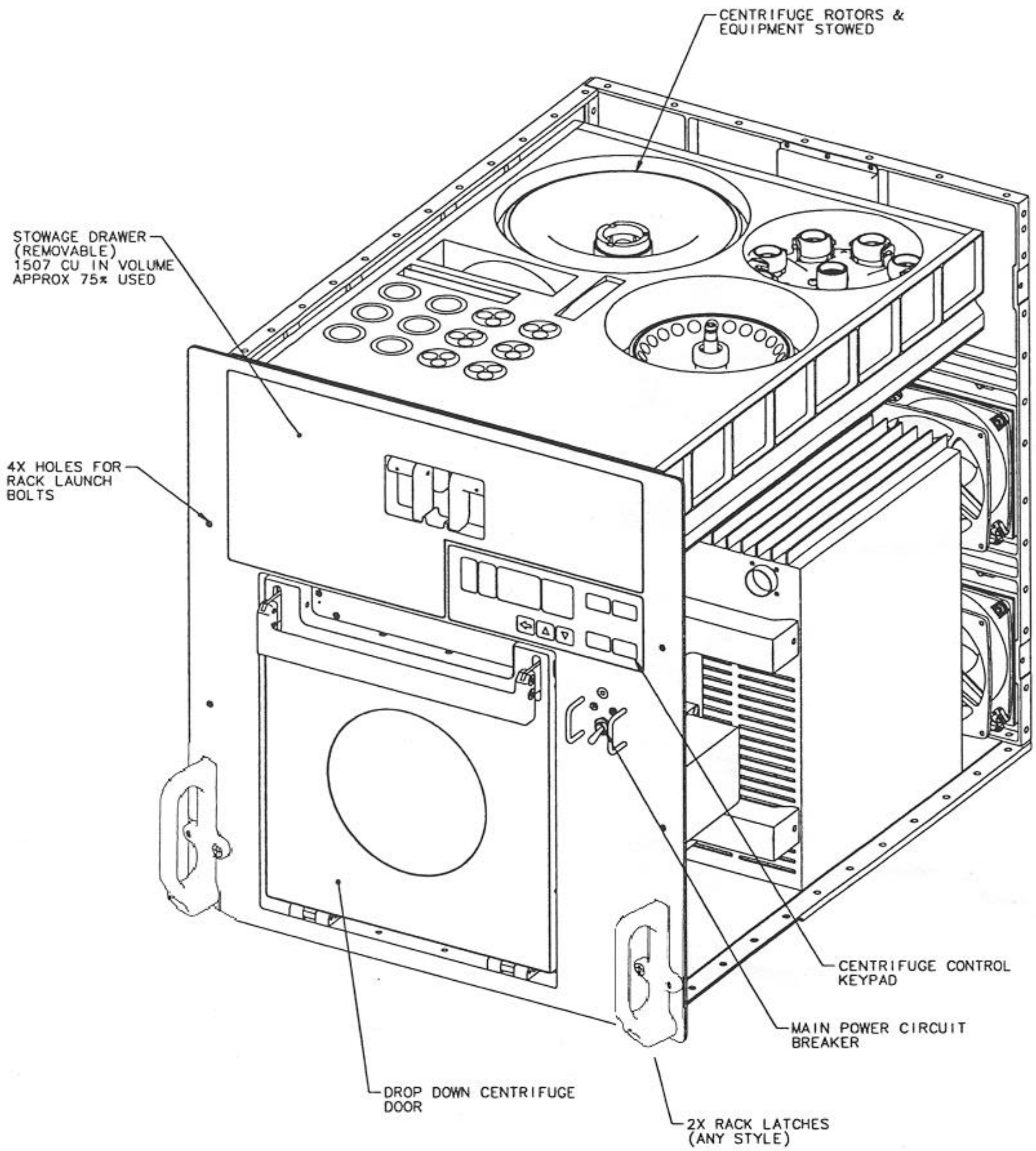


**Figure 1 Refrigerated Centrifuge Assembly**

## 2.0 FRACTURE CONTROL ASSESSMENT

Refrigerated Centrifuge panels are made of 7075-T7351 Aluminum. These panels are connected together by National Aerospace Standard (NAS) fasteners. All these panels and the fasteners are analyzed for launch and landing loads and have positive margins of safety. These panels and fasteners are classified as fail-safe by engineering judgment/analysis.

### 2.1 Crew-Induced Loads Analysis

The RC Front Door and the Stowage Drawer Front Panel are determined to be the weakest and the most vulnerable part for kick load. A 125 lb force is applied over a 4 inch x 4 inch square area. Analysis results show positive margins of safety. A crew-induced load of 50 lb is applied on the Front Handles. Analysis result shows positive margin of safety.

### 2.2 Fail-Safe Analysis

There are seven failure modes considered for the fail-safe analysis. These are (1) front panel to rack, (2) slide to side panel, (3) floating plate to bottom panel, (4) motor mounting ring to support assembly, (5) power controller module to bottom panel, (6) compressor to floating plate, and (7) condenser to floating plate. For all the cases the highly loaded fastener is assumed to be failed and the load normally carried by this fastener is now redistributed to the other fasteners. In all the cases analysis results show positive margins with a factor safety of 1.0.

### 2.3 Safe Return Configuration Analysis

According to the interpretation letter TA-93-037, "Structural Integrity Following Mechanism Failure", mechanism failure(s) which result in limit load redistribution will require structural verification on the redistributed loads if the failed condition is credible. When two-failure tolerance cannot be implemented, structural verification of the redistributed load path is required and the 1.4 factor of safety on limit loads must be maintained.

For the RC, the two credible failures are (1) floating plate to bottom panel fastener failure and (2) motor mounting ring to support assembly fastener failure. During on orbit operation the fasteners that connect the floating plate to the bottom panel and the ones that connect the motor mounting ring to support assembly will be removed to allow the vibration isolators to be in effect. In case of landing these fasteners should be reinstalled to overcome the flexibilities of the isolators. Analysis results show positive margins of safety with a factor of safety of 1.4

### 2.4 Containment Analysis

For containment analysis, it must be shown that no part can attain sufficient kinetic energy to escape a container, which completely encompasses the part in order to prevent any hazard to the STS/ISS or crew (Ref. SSP 52005B, Section 6.2.1.1). The heaviest mass inside the RC drawer is the compressor, which is about 23.0 lb. In Section 2.2 it is shown that the floating plate, motor mounting ring, power controller module, compressor, and condenser connections are fail-safe. Therefore no containment analysis is necessary for these items.

The next heaviest item is the rotor stowed in the stowage drawer. The heaviest rotor has a mass of approximately 4.5 lb. A containment analysis is performed by assuming that this rotor is released from the stowage drawer and impacts the stowage drawer front panel. The result shows the stowage drawer front panels are adequate enough to contain the heaviest rotor. Detailed analysis is shown in Appendix A.

### 2.5 Depressurization/Repressurization Analysis

A depressurization/repressurization analysis is performed based on the requirements in SSP 57000, Revision D, Paragraph 3.1.1.2. The maximum delta pressure experienced during the depressurization and is negligible (0.00042 psi). In other words, the leak area is sufficient to prevent significant delta pressure build-up during depressurization or repressurization event. If this differential pressure is applied to the largest area and the smallest thickness panel, which is the top panel, which has an area of 401 $in^2$, the force imparted is only 0.168 lb. As a result, it can be stated that the effect of depressurization/repressurization is negligible.

### 2.6 Fatigue Analysis

A fatigue analysis of the RC is performed using NASA/FLAGRO crack growth program. Goddard load spectrum which is embedded within the program is used for the analysis. For the RC, the highly loaded element is the front panel flange, which is connected to the other panels is considered for the fatigue analysis. This section is 0.13 inch thick, 2.251 inch wide and has 0.23 inch diameter fastener holes. An initial corner crack size of 0.005 inch is used in this analysis. A tensile stress of 6.862 ksi, a bending stress of 23.359 ksi, and a bearing stress of 14.214 ksi on the front panel flange is used in this analysis. The result of the fatigue analysis is shown in Appendix B. The final fatigue life of the RC after applying a scatter factor, 4.0 is 16 missions.

## 2.7 Pressure System

The pressure system in the Refrigerated Centrifuge is the refrigeration unit. The refrigeration method utilized by the RC is vapor compression cycle. Vapor compression systems consist of four components: a compressor, a condenser, an evaporator, and an expansion device (See Figure 2.

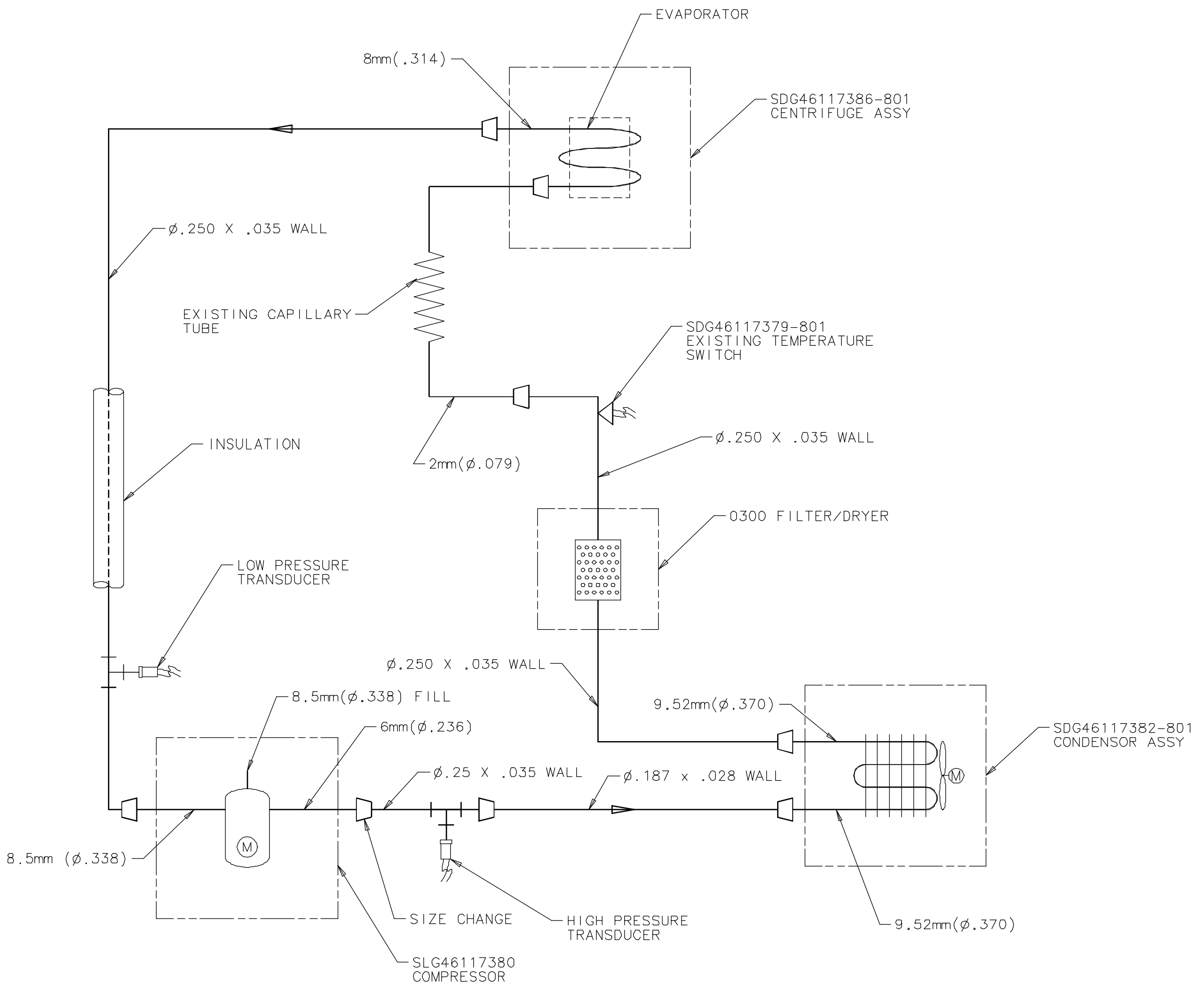


**Figure 2 Refrigerated Centrifuge Pressure System Flow Diagram**

The compressor takes low pressure, low temperature refrigerant gas and compresses it to high pressure, high temperature gas. Reciprocating pistons intake vapor at low pressure, and compress the vapor before sending it to the discharge line. From the compressor, the hot, high-pressure gas travels through the discharge line into the condenser. The condenser is the part of the system where the heat is rejected by, as the name implies, condensation. As the hot gas refrigerant cools, drops of liquid refrigerant form within the coil. Eventually, when the gas reaches the end of the condenser, it has condensed completely, that is, only liquid refrigerant is present.

The purpose of the expansion device in a vapor-compression refrigeration cycle is to control the flow of refrigerant to the evaporator. As the refrigerant leaves the condenser, it has cooled, and condensed to liquid, but is still under high pressure. In order for the liquid to absorb the necessary heat in the evaporator, its pressure must be reduced, which is accomplished within the expansion device. The refrigerated centrifuge uses a capillary tube to accomplish this. The evaporator is the component of the cycle, which actually absorbs the heat from the conditioned space. The evaporator is similar in construction to the condenser, but its function is opposite. As the fluid leaves the expansion device, it is a cool liquid. As it passes through the evaporator, it picks up heat from the room, and evaporates into a gaseous form. This evaporation is what enables the refrigerant to absorb the heat energy from the room.

As the refrigerant leaves the evaporator, it is returned to the cooled, low-pressure state, and is sent back to the compressor to begin the cycle again. Under normal circumstances the refrigerant will not wear out, it will be reused again and again, changing its physical form, but not its chemical composition. The refrigerated centrifuge uses R404a as its working fluid. R404a is environmentally friendly and has been given a toxicity level of 0 (reference memo #458). The pressure matrix for the RC is shown in Table 1. The Leak-Before-Burst (LBB) calculations for the fluid lines will be included in the final report.

### 2.8 Rotating Equipments

There are three fans in the Refrigerated Centrifuge assembly. There are two fans, P/N SEG46116060-702, which are mounted to the rear panel are HRF common fans. These fans measure 4.69 x 4.69 inches in size and spin at 5200 rpm at 28 VDC. If the fan speed is linearly extrapolated out to determine the worst-case speed at 32 VDC, then the speed will be 5943 rpm. The third fan, P/N W2E142-CC13-16 is connected to the condenser is a tubeaxial fan. This fan has a size of 5.91 x 6.77 inches and rotates at 2700 rpm at 115 VAC. For all the fans the size is less than 8 inches and maximum speed is less than 8000 rpm. Therefore, a containment analysis is not necessary.

The rotor motor and the rotor will be addressed in the final fracture control summary report.

## Table 1 Refrigerated Centrifuge Pressure Matrix

| **Pressure Matrix** | | | | | | |
|---|---|---|---|---|---|---|
| After two-fault failure, maximum system pressure is still controlled to be NO MORE THAN 350 psi | | | | | | |
| | | | | | | |
| **Tubes, All Copper** | | | | | | |
| **Size** | **Usage** | **MDP (psig)** | **(Burst) Pressure (psig)** | **Testing Organization** | **Reqd. FOS** | **Actl. FOS** |
| 2 mm | Capillary Tube | 350 | 12000 | ASME Refrigeration Piping Handbook | 4.0 | 34.3 |
| 3/16" (5 mm) | Discharge | 350 | 10000 | Tested by LM | 4.0 | 28.6 |
| 1/4" (6 mm) | Suction | 150 | 6900 | Tested by LM | 4.0 | 46.0 |
| 5/16" (8 mm) | Evaporator | 150 | 1200 | Tested by LM | 4.0 | 8.0 |
| 3/8" (10 mm) | Condenser | 350 | 1700 | ASME Refrigeration Piping Handbook | 4.0 | 4.9 |
| Fittings | P. Transducer | 350 | 1500 | Based on manufacturer data | 4.0 | 4.3 |
| Pressure Transducers | Control | 350 | 1000 | Based on manufacturer data | 2.5 | 2.9 |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| **Filter/Drier** | | | | | | |
| **Part No.** | **Manufacturer** | **MDP (psig)** | **Burst Pressure (psig)** | **Test Org.** | **Reqd. FOS** | **Actl. FOS** |
| C-032-S | Sporlan | 350 | >2500 | UL | 2.5 | 7.1 |
| | | | | | | |
| | | | | | | |
| **Compressor Housing** | | | | | | |
| **Part No.** | **Manufacturer** | **MDP (psig)** | **Burst Pressure (psig)** | **Test Org.** | **Reqd. FOS** | **Actl. FOS** |
| AE820AT-900-J7 | Tecumseh | 150 | >400 | LM | 2.5 | 2.7 |

## 3.0 SUMMARY

There is no fracture critical item in the Refrigerated Centrifuge. There is no glass, sealed container, or structural composite. All the panels and the fasteners connecting the panels together are classified as fail-safe. The RC stowage drawer will act as a structural containment for the stowed mass. The fracture control dispositions for all the items are shown in Table 2. RC meets all the fracture control requirements and is qualified for flight in EXPRESS Rack.

**Table 2 Fracture Control Disposition Summary**

| ITEM OR PART | PART NUMBER | MATERIAL | NUMBER & TYPE OF CONNECTIONS | SAFETY FACTOR | CLASSIF-ICATION | NOTE |
|---|---|---|---|---|---|---|
| | | | | | | |
| Top Panel | SDG46114565-001 | 7075-T7351 Aluminum | 38 NAS1102-3 | 36.28 | NFC (FS) | 1 |
| Bottom Panel | SDG46117378-301 | 7075-T7351 Aluminum | 38 NAS1102-3 | 2.396 | NFC (FS) | 1 |
| Right Side Panel | SDG46117367-301 | 7075-T7351 Aluminum | 48 NAS1102-3 | 3.804 | NFC (FS) | 1 |
| Left Side Panel | SDG46117367-301 | 7075-T7351 Aluminum | 48 NAS1102-3 | 4.229 | NFC (FS) | 1 |
| Front Panel | SDG46117366-301 | 7075-T7351 Aluminum | 38 NAS1102-3 | 2.223 | NFC (FS) | 1 |
| Rear Panel | SDG46117369-301 | 7075-T7351 Aluminum | 38 NAS1102-3 | 2.809 | NFC (FS) | 1 |
| Front Door | SEG46117371-301 | 7075-T7351 Aluminum | 2 Latches & 2 Hinges | 25.33 | NFC (FS) | 1 |
| Stowage Drawer | SEG46117716-301 | 7075-T7351 Aluminum | 63 NAS1101-08 | 5.532 | NFC (FS) | 1 |
| Floating Plate | SDG46117388-301 | 7075-T7351 Aluminum | 4 NAS1351N4 | 22.16 | NFC (FS) | 2 |
| Support Assembly | SDG46117386-801 | 7075-T7351 Aluminum | 8 NAS1101-3 | 5.194 | NFC (FS) | 1 |
| Motor Mounting Ring | SDG46117391-301 | 7075-T7351 Aluminum | 3 NAS1351N4 | 11.86 | NFC (FS) | 2 |
| Slide | SEG46117459-301 | 7075-T7351 Aluminum | 12 NAS1101-3 | 5.298 | NFC (FS) | 2 |
| Internal Components | | | | | Contained | 3 |
| Pressure System | | | | | Pressurized Component | 4 |
| Fans | SEG46116060-702<br>W2E142-CC13-16 | | 2<br>1 | | Contained | 5 |

**Table 2 Fracture Control Disposition Summary *Concluded***

| ITEM OR PART | PART NUMBER | MATERIAL | NUMBER OF CONNECTIONS | SAFETY FACTOR | CLASSIF-ICATION | NOTE |
|---|---|---|---|---|---|---|
| | | | | | | |
| Top Panel Fasteners | NAS1102-3 | CRES A286 | 38 | 1.838 | NFC (FS) | 1 |
| Bottom Panel Fasteners | NAS1102-3 | CRES A286 | 38 | 1.725 | NFC (FS) | 1 |
| Right Side Panel Fasteners | NAS1102-3 | CRES A286 | 48 | 1.688 | NFC (FS) | 1 |
| Left Side Panel Fasteners | NAS1102-3 | CRES A286 | 48 | 1.600 | NFC (FS) | 1 |
| Front Panel Fasteners | NAS1102-3 | CRES A286 | 38 | 1.600 | NFC (FS) | 1 |
| Rear Panel Fasteners | NAS1102-3 | CRES A286 | 38 | 1.788 | NFC (FS) | 1 |
| Stowage Drawer Fasteners | NAS1102-3 | CRES A286 | 63 | 1.463 | NFC (FS) | 1 |
| Support Assembly Fasteners | NAS1102-3 | CRES A286 | 8 | 1.788 | NFC (FS) | 1 |
| Front Panel to Rack Bolt | NAS1351N4 | Heat-Res. Steel | 6 | 1.584 | NFC (FS) | 2 |
| Motor Ring to Support Assy. Bolt | NAS1351N4 | Heat-Res. Steel | 3 | 1.610 | NFC (FS) | 2 |
| Floating Plate to Bottom Panel Bolt | NAS1351N4 | Heat-Res. Steel | 4 | 1.520 | NFC (FS) | 2 |
| Slide to Side Panel Bolt | NAS1101-3 | CRES A286 | 12 | 1.800 | NFC (FS) | 2 |
| Power Controller to Bottom Panel Bolt | NAS1101-3 | CRES A286 | 4 | 1.762 | NFC (FS) | 2 |
| Compressor to Floating Plate Bolt | NAS1351N4 | Heat-Res. Steel | 4 | 1.615 | NFC (FS) | 2 |
| Condenser to Floating Plate Bolt | NAS1101-3 | CRES A286 | 4 | 1.954 | NFC (FS) | 2 |

NOTE 1: These items are connected with multiple fasteners and there is redundant load path. Fail-safe by engineering judgment.
NOTE 2: Fail-safe analysis and safe return configuration analysis are performed.
NOTE 3: See the containment analysis in Appendix A.
NOTE 4: See the pressure system description in Section 2.7.
NOTE 5: These fans are less than 8 inches in size and are less than 8000 rpm in speed.

# APPENDIX A

## CONTAINMENT ANALYSIS

## A.0 CONTAINMENT ANALYSIS

For containment analysis, it must be shown that no part can attain sufficient kinetic energy to escape a container, which completely encompasses the part in order to prevent any hazard to the STS/ISS or crew (Ref. SSP 52005B, Section 6.2.1.1). The heaviest mass inside the RC drawer is the compressor, which is about 23.0 lb. In Section 7.0 it is shown that the floating plate, motor mounting ring, power controller module, compressor, and condenser connections are fail-safe. Therefore no containment analysis is necessary for these items. The next heaviest item is the rotor stowed in the stowage drawer. The heaviest rotor has a mass of approximately 4.5 lb.

A containment analysis is performed by assuming that this rotor is released from the stowage drawer and impacts the stowage drawer front panel. The front panel is 0.0625 inch thick. The worst-case net cg acceleration of 4.7g from MPLM Delta Design Cycle Couple Loads Analysis is used in the analysis, which is more conservative than the 1.5g suggested in SSP 52005B. It is assumed that the rotor with a nose radius of 0.5 inch travels 18 inches before it reaches the front panel. Structural containment is demonstrated using the following equation commonly referred to as the "Punch" equation.

$$T_R = \left[\frac{1}{2} * V^2 * \frac{W}{g} * \frac{1}{\pi d YSw}\right]^{[1/2]}$$

Where,

$T_R$ = Maximum required wall thickness (inches) of the container to prevent escape of the component/part

W = Weight (pound-force) of the detached piece or part to be contained

g = Gravitational acceleration (inch per second squared)

V = Velocity (inches per second) that may be attained by that piece or part

d = Minimum profile diameter (inches) of piece or part that will produce a shear load on the container wall before escape by any particular piece or part resulting from a structural failure

$YS_W$ = Yield strength (pound per square inch) of the container wall material

Velocity attained by the payload is computed by the following equation:

$V = \sqrt{2aS_d}$

Where,

a = Steady state acceleration = 4.7 g

Sd = Maximum travel distance of the rotor = 18 in

$V = \sqrt{2 * 4.7 * 32.2 * 12 * 18}$ = 255.693 in/sec

The front panel is made of 7075-T7351 Aluminum alloy and has yield strength of 57000 psi. Calculating the required thickness for containment:

$$T_R = \left[\frac{1}{2} * 255.693^2 * \frac{4.5}{32.2 * 12} * \frac{1}{\pi * 1.0 * 57000}\right]^{[1/2]}$$

$T_R$ = 0.0461 in

Comparing the computed required thickness (0.0461 in) to the actual thickness of the front panel (0.0625 in), the actual thickness is higher. As a result, no penetration will occur.

# APPENDIX B

## FATIGUE ANALYSIS

## B.0 FATIGUE ANALAYSIS

FATIGUE CRACK GROWTH ANALYSIS

DATE: 10/11/00 TIME: 14:43:08

(Computed: NASGRO Version 3.0.5, Apr 2000.)

U.S. customary units [inches, ksi, ksi sqrt(in)]

PROBLEM TITLE

RC FATIGUE LIFE ANALYSIS

Crack Growth Model: Non Interaction
Equation/Table : NASGRO Equation

GEOMETRY

MODEL: CC02-Corner crack from hole in plate (2D).

```
Plate Thickness, t  =    0.1300
Plate Width, W      =    2.2510
Hole Diameter, D    =    0.2300
Edge to Hole Ctr, B =    0.3300
Poisson s ratio     =    0.33
```

FLAW SIZE: (User specified)

```
a   (init.) =  0.5000E-02
c   (init.) =  0.5000E-02
a/c (init.) =   1.000
```

MATERIAL

MATL 1: 7075-T7351
Plt & Sht; L-T

Material Properties:

| Matl No. | UTS | YS | K1e | K1c | Ak | Bk | Thk | Kc | Keac |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 71.0 | 62.0 | 41.0 | 29.0 | 1.00 | 1.00 | 0.130 | 56.4 | |

| Matl No. | Crack Growth Eqn Constants | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | C | n | p | q | DKo | Cth+ | Cth- | Rcl | Alpha | Smax/SIGo |
| 1 | 0.348D-07 | 2.529 | 0.50 | 1.00 | 2.60 | 2.00 | 0.10 | 0.70 | 1.90 | 0.30 |

```
RC FATIGUE LIFE ANALYSIS
MODEL: CC02

FATIGUE SCHEDULE BLOCK INPUT TABLE
---------------------------------
GODDARD SPECTRUM                                                   ~

[Note: Stress = Input Value * Scale Factor]

Stress Scaling Factors for Block Case:  1

Scale Factor for Stress S0:   0.68620E-01
Scale Factor for Stress S1:   0.23359
Scale Factor for Stress S3:   0.14214

Schedule info. was input manually

Total No. of Blocks in Schedule =     1

   Block Number and Case Correspondences
 Block Number                 Block Case No.
From   -   To
    1   -     1                        1

Stresses: Tension, bending or pin

--------------------------------
```

RC FATIGUE LIFE ANALYSIS
MODEL: CC02

FATIGUE SCHEDULE BLOCK INPUT TABLE
----------------------------------
GODDARD SPECTRUM ~

SINGLE DISTINCT BLOCK

| STEP | MATL | NUMBER OF FATIGUE CYCLES | S0 (t1) | S0 (t2) | S1 (t1) | S1 (t2) |
|---|---|---|---|---|---|---|
| 1 | 1 | 2.00 | -100.00 | 100.00 | -100.00 | 100.00 |
| 2 | 1 | 4.00 | -90.00 | 90.00 | -90.00 | 90.00 |
| 3 | 1 | 8.00 | -80.00 | 80.00 | -80.00 | 80.00 |
| 4 | 1 | 15.00 | -70.00 | 70.00 | -70.00 | 70.00 |
| 5 | 1 | 49.00 | -60.00 | 60.00 | -60.00 | 60.00 |
| 6 | 1 | 81.00 | -50.00 | 50.00 | -50.00 | 50.00 |
| 7 | 1 | 178.00 | -40.00 | 40.00 | -40.00 | 40.00 |
| 8 | 1 | 641.00 | -30.00 | 30.00 | -30.00 | 30.00 |
| 9 | 1 | 3120.00 | -20.00 | 20.00 | -20.00 | 20.00 |
| 10 | 1 | 3405.00 | -10.00 | 10.00 | -10.00 | 10.00 |
| 11 | 1 | 5019.00 | -7.00 | 7.00 | -7.00 | 7.00 |
| 12 | 1 | 28853.00 | -5.00 | 5.00 | -5.00 | 5.00 |
| 13 | 1 | 91655.00 | -3.00 | 3.00 | -3.00 | 3.00 |

| STEP | MATL | NUMBER OF FATIGUE CYCLES | S3 (t1) | S3 (t2) | S (t1) | S (t2) |
|---|---|---|---|---|---|---|
| 1 | 1 | 2.00 | -100.00 | 100.00 | -100.00 | 100.00 |
| 2 | 1 | 4.00 | -90.00 | 90.00 | -90.00 | 90.00 |
| 3 | 1 | 8.00 | -80.00 | 80.00 | -80.00 | 80.00 |
| 4 | 1 | 15.00 | -70.00 | 70.00 | -70.00 | 70.00 |
| 5 | 1 | 49.00 | -60.00 | 60.00 | -60.00 | 60.00 |
| 6 | 1 | 81.00 | -50.00 | 50.00 | -50.00 | 50.00 |
| 7 | 1 | 178.00 | -40.00 | 40.00 | -40.00 | 40.00 |
| 8 | 1 | 641.00 | -30.00 | 30.00 | -30.00 | 30.00 |
| 9 | 1 | 3120.00 | -20.00 | 20.00 | -20.00 | 20.00 |
| 10 | 1 | 3405.00 | -10.00 | 10.00 | -10.00 | 10.00 |
| 11 | 1 | 5019.00 | -7.00 | 7.00 | -7.00 | 7.00 |
| 12 | 1 | 28853.00 | -5.00 | 5.00 | -5.00 | 5.00 |
| 13 | 1 | 91655.00 | -3.00 | 3.00 | -3.00 | 3.00 |

Environmental Crack Growth Check for Sustained Stresses
(Kmax less than Keac): NOT SET
-------

RC FATIGUE LIFE ANALYSIS
MODEL: CC02

FATIGUE SCHEDULE BLOCK STRESS TABLE

GODDARD SPECTRUM ~

| STEP | MATL | NUMBER OF FATIGUE CYCLES | S0 (ksi) (t1) | S0 (ksi) (t2) | S1 (ksi) (t1) | S1 (ksi) (t2) |
|---|---|---|---|---|---|---|
| 1 | 1 | 2.00 | -6.86 | 6.86 | -23.36 | 23.36 |
| 2 | 1 | 4.00 | -6.18 | 6.18 | -21.02 | 21.02 |
| 3 | 1 | 8.00 | -5.49 | 5.49 | -18.69 | 18.69 |
| 4 | 1 | 15.00 | -4.80 | 4.80 | -16.35 | 16.35 |
| 5 | 1 | 49.00 | -4.12 | 4.12 | -14.02 | 14.02 |
| 6 | 1 | 81.00 | -3.43 | 3.43 | -11.68 | 11.68 |
| 7 | 1 | 178.00 | -2.74 | 2.74 | -9.34 | 9.34 |
| 8 | 1 | 641.00 | -2.06 | 2.06 | -7.01 | 7.01 |
| 9 | 1 | 3120.00 | -1.37 | 1.37 | -4.67 | 4.67 |
| 10 | 1 | 3405.00 | -0.69 | 0.69 | -2.34 | 2.34 |
| 11 | 1 | 5019.00 | -0.48 | 0.48 | -1.64 | 1.64 |
| 12 | 1 | 28853.00 | -0.34 | 0.34 | -1.17 | 1.17 |
| 13 | 1 | 91655.00 | -0.21 | 0.21 | -0.70 | 0.70 |

| STEP | MATL | NUMBER OF FATIGUE CYCLES | S3 (ksi) (t1) | S3 (ksi) (t2) | S (ksi) (t1) | S (ksi) (t2) |
|---|---|---|---|---|---|---|
| 1 | 1 | 2.00 | -14.21 | 14.21 | -14.21 | 14.21 |
| 2 | 1 | 4.00 | -12.79 | 12.79 | -12.79 | 12.79 |
| 3 | 1 | 8.00 | -11.37 | 11.37 | -11.37 | 11.37 |
| 4 | 1 | 15.00 | -9.95 | 9.95 | -9.95 | 9.95 |
| 5 | 1 | 49.00 | -8.53 | 8.53 | -8.53 | 8.53 |
| 6 | 1 | 81.00 | -7.11 | 7.11 | -7.11 | 7.11 |
| 7 | 1 | 178.00 | -5.69 | 5.69 | -5.69 | 5.69 |
| 8 | 1 | 641.00 | -4.26 | 4.26 | -4.26 | 4.26 |
| 9 | 1 | 3120.00 | -2.84 | 2.84 | -2.84 | 2.84 |
| 10 | 1 | 3405.00 | -1.42 | 1.42 | -1.42 | 1.42 |
| 11 | 1 | 5019.00 | -0.99 | 0.99 | -0.99 | 0.99 |
| 12 | 1 | 28853.00 | -0.71 | 0.71 | -0.71 | 0.71 |
| 13 | 1 | 91655.00 | -0.43 | 0.43 | -0.43 | 0.43 |

Environmental Crack Growth Check for Sustained Stresses
(Kmax less than Keac): NOT SET

```
RC FATIGUE LIFE ANALYSIS
MODEL: CC02

ANALYSIS RESULTS:
-----------------


 Schdl  Block         Cycles     Final Flaw Size           K max
        Step                       a        c          a-tip    c-tip

10        1           1330300.  0.00948  0.00959      12.032    12.059
20        1           2660600.  0.01948  0.01973      14.516    14.622
30        1           3990900.  0.03402  0.03534      15.717    16.231
40        1           5321200.  0.05123  0.05617      16.410    17.750
50        1           6651500.  0.07063  0.08509      16.973    19.912
60        1           7981800.  0.09175  0.13024      17.445    23.504

FINAL RESULTS:
Crack outside geometric bounds:
c =   0.2154      B - D/2 =   0.2150
at Cycle No.      2302.69
of Load Step No.      9      Description: None
of Block No.          1
of Schedule No.      67
Crack Sizes:  a =  0.114792      , c =  0.215358     , a/c =   0.5330
Total Cycles =  8783260.7


Execution time (hh:mm:ss): 00:00:01.0
Note: this is elapsed wall-clock time, not CPU time!
```